smoke. We see that the year 1834 falls in the dry period of 1826–1845.

Not only does the Marshall graph of tree ring growth by pentads since 1675, by preponderance of evidence, support his determination of these brief, alternately wet and dry cycles, but it shows in a rather conspicuous way the degree of wetness or dryness. For instance, probably due to excessive rains or snows, comparatively heavy growth is shown for the periods 1706–1745 and 1786–1825. Very light growths were indicated for 1760–1770. But the most striking truth brought out in this tree-ring investigation is that in all ages of trees there has been a radical decline of tissue growth since 1885, except that this decline was materially halted in all ages of trees considered from about 1896 to 1902. This spurt of growth during the final decline is accurately reflected in the Spokane weather records for the years 1896 to 1902, which, despite a rather dry 1898, show average precipitation of 18.75, more than 2.00 inches above the present Spokane normal. Notwithstanding those recent seven wet years, Mr. Marshall concludes that the 40 years from 1885 to 1925, where his investigation ended, were by far drier than any similar period in the last 280 years.

Thus we find two neighboring counties, whose settings are meteorologically homogeneous, presenting diametrically opposite precipitation cycle evidence. The Granite Lake stumps point to a dry past of unknown origin terminating within the last two or three decades. The Priest River trees show no dry period in the last 280 years approaching in severity that of the last five decades. How could Granite and Silver Lakes trees grow at such low water levels while the Priest River Basin was enjoying heavy precipitation?

The proper solution of this enigma would be of much scientific interest as well as economic importance. Such a solution should without doubt consider the following.

Marshall's careful determinations of alternate wet and dry cycles by ring growth in more than 50 white pine trees in Bonner County are closely paralleled in similar determinations of ring growths in 23 Douglas firs 25 miles northeast of Portland, Oreg., whose age was approximately 210 years. From a table [3] by A. E. Douglas measurements indicate corresponding heavy growths in Marshall's wet periods and corresponding light growths in his dry periods. Between the white pine site in Bonner County and Granite Lake in Spokane County are numerous fresh water lakes now at unprecedented low water on whose banks ancient stumps are not revealed. This absence of old stumps on lakes to the north of Spokane needs adequate explanation. Is it not possible that the lava bed lakes now showing stumps have at some time in the past had a common subterranean outlet active at the time of the production of the old trees? Then also is it not possible that by some slight geological movement this outlet could have been in recent years blocked? Thus may these lakes have been filled and the trees killed. The present low water need not be accounted for by a reopening of the subterranean outlet, but by the general drought of the last few decades.

A complete solution of this riddle should take also into consideration a chemical analysis of the waters, and a study of the biology and geology of all the lava bed lakes. Also a correlation of the rings of the old stumps with those higher up on the slopes and with those of the Marshall white pines and the Douglas Oregon firs, while probably not likely to be convincing, would be of intense interest.

[3] See Climatic Cycles and Tree-Growth, by A. E. Douglas, Carnegie publication No. 289.

TULARE LAKE [1]—A CONTRIBUTION TO LONG-TIME WEATHER HISTORY

By C. E. GRUNSKY, Eng. D.

[1930]

In making a study of the water resources of the San Joaquin Valley, Calif., for the State engineer department, during the years 1881 to 1888, certain interesting facts were developed by the writer which should be more widely known, because they throw some light upon the weather conditions in Central California, or, more particularly, in the southerly San Joaquin Valley watershed, preceding any historical records. The facts to which attention will be directed relate to Tulare Lake which, during the last 30 years, has been repeatedly dry. In consequence of this condition the assumption is now generally made that the lake is a thing of the past; that its dry bed for the most part at least will remain dry hereafter.

That this assumption is premature and that the lake may at some unknown time in the future again attain a high stage will appear from a review of the history of the lake which had best be given by reference to the facts as they came to my attention. In 1881 and the years following I had occasion to make a number of visits to the lake region after having informed myself from maps and reports of the topography and behavior of streams in the watershed and in the immediate vicinity of the lake. It will be recalled in this connection that Kings River which drains a large watershed on the western slope of the Sierra Nevada Mountains, enters the San Joaquin Valley at a point easterly from Fresno. The course of the river across the valley, or, rather, across the broad east side plain of the valley, is southwesterly. At a point about midway of its course across this plain the delta formation of the river begins. The river, before its course was modified by human agency, sent some of its flood flow into numerous overflow or high water channels of which those toward the south discharged into the depression in which Tulare Lake lies and those toward the north were tributary to San Joaquin River. At low water stages, during the period when Tulare Lake is not overflowing, the discharge of Kings River is into the lake.

The delta of Kings River has been built up by the sand and silt which the river has brought into the valley, forming a broad flat-topped delta ridge which extends across the trough or lowest part of the San Joaquin Valley now appearing in the topography as a flat dam or barrier miles in width. Upstream or south from this barrier the original valley trough is at materially lower elevation than the lowest point on the crest of the ridge. A saucerlike depression has thus been formed upstream from the delta of Kings River. The water trapped in this depression forms Tulare Lake.

Probably 100 square miles of the lake bed are at about elevation 179 feet above mean sea level. The lake was at a very high stage in 1853 after several seasons with more than ordinary rainfall. Thereupon there was a

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FIGURE 1.—Willow stumps in Tulare Lake bed, 1882. Grunsky

gradual recession of the lake with a drop in its water surface to about elevation 200 feet in the fall of 1861. The highest lake stage followed immediately. It was produced by the very wet winter of 1861–62 and the same stage was attained a second time in 1868, both at about elevation 216 feet, at which stage the maximum depth of water in the lake was about 37 feet. The area of the lake at this high stage was about 750 to 800 square miles. At elevation about 206 feet, water from the lake under ordinary conditions could flow northerly in a well defined channel toward the Fresno Swamp and thence into the San Joaquin River and at about elevation 210 feet the water of the lake over-topped the lowest point on the Kings River delta ridge. At the lake's highest stage about 6 feet of water was flowing in a broad expanse northerly over this ridge.

Information, received by me (1881 and 1882) from some of the farmers in the vicinity of Hanford—in the Mussel Slough country—was to the effect that the lake had reached an unusually low stage and that its recession had laid bare an area near the mouth of Mussel Slough, at the lake margin, covered with stumps of trees. This information prompted an investigation, with the result that these stumps were found and sketches were made (1882). The ground on which they stood is at about elevation 197, or about 22 feet below the highest known stage of the lake. At this point there was clear evidence of the location of an old channel entering the lake area from a northeasterly direction. Undoubtedly this was at one time one of the channels of Mussel Slough, most likely its principal channel, during a protracted period in which the lake was at or even below its then low stage.

There were about 100 stumps to be seen. These were probably all willow tree stumps. Their tops were ragged as though the trees had been broken off. They stood in part at the south side of the old slough channel, upon ground the surface of which ranged from the water's edge to perhaps 1 foot above the water surface. Some stumps were, in fact, on ground still covered with water. I tied my horse to one of the stumps and took time for a sketch which is the basis of the illustration which accompanies this paper.

Some of these stumps had a diameter of about 4 feet. Their dimensions and their position indicated that they were the remnants of a grove of willows which had reached mature growth along the bank of the water course and along the margin of the lake. It may safely be assumed that low lake stages with conditions favorable to the growth of these willows must have been continuous for a period of some 40 or 50 years or perhaps much longer. There was here then positive evidence that, at some time in the past before the arrival of the white man on the scene, the lake had been at or below the elevation of about 195 feet above sea level for a long period of time. The elevation here noted was ascertained by a survey made by me for this purpose in the fall of the following year (1883).

Furthermore, after the lake rose to a stage high enough to drown this willow growth, it remained at or above this stage for 50 or 100 or more years keeping the stumps, after the trees had died and had been broken off, submerged until their discovery about 50 years ago. The long period of persistently light or moderate rainfall favoring the growth of the willows was followed by a long period in which the frequency of fairly wet winters kept the lake at fairly high stages, culminating as noted, with the very high waters of 1853, 1862, and 1868.

With the information relating to so much of the history of the lake as disclosed by the willow stumps as a background, I interviewed some of the oldest residents of the lake region—among others Mr. Daniel Rhoads, of Lemoore. He informed me that there was an old Indian tradition to the effect that many years ago the lake had dried up. The Indians could cross from the east to the west side of the valley between two small ponds of water.

It was from Mr. Rhoads and others that information was also obtained relating to the stage of the lake prior to the very wet winter 1861–62 and also relating to the high water stage following this winter and a second very high stage in the year 1868.

It developed from this inquiry that enough water was discharged in the single season 1861–62 by Kern River, Tule River, Kaweah River, Kings River, and a number of lesser streams into the lake basin to raise the lake's water surface 16 feet. The lake, by reason of this inflow of storm water, was increased in surface area from about 350 square miles in 1861 to nearly 800 square miles in 1862. Moreover as the lake approached its highest stage some of its water went out through the outlet channel already referred to and over the top of the Kings River delta ridge northerly into the Fresno Swamp and thence into San Joaquin River. No determination of the volume of water that thus flowed northerly out of the lake basin has been attempted.

It is, however, readily estimated from the lake stages before and after the winter of 1861–62 that there must have been an inflow of water into the lake region in a single season 1861–62 of more than 5,000,000 acre-feet of water. While the water surface elevation of the lake as determined by survey in 1883 was called its lowest known stage by everyone familiar with the lake, the weather conditions since then have failed to maintain the lake even at that level. With many minor fluctuations, the lake has gradually dwindled in size. Its water surface became lower and in the fall of 1898 the lake bed was bare.

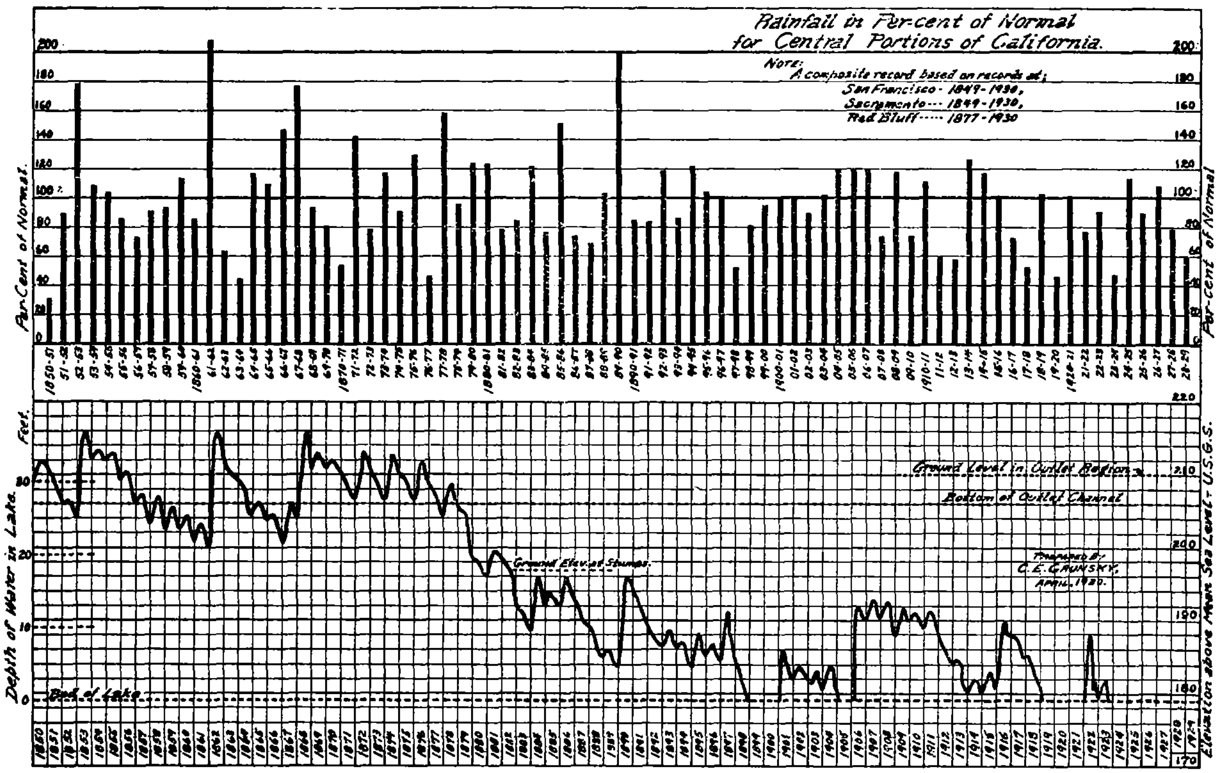
Learning of this fact I made a second survey early in 1899 to determine by spirit leveling just what the elevation of the bed of the lake is. It was found to be about 179 feet. Since that time water has reached the lake area practically every year, but not always in quantity to exceed the annual evaporation.

It is natural that the shrinking of the lake and present conditions in the lake region should be attributed by many to the diversion, for irrigation, of the water naturally in the streams which flow into the lake area. While this use must, in some measure, reduce the quantity of water delivered into the lake, its effect during seasons of large water production will be almost negligible.

When, in the light of the above facts, it is recalled that the highest lake stages were preceded by a very long period of low lake stages which must be taken to indicate a very long period with winter rainfall but little above or at, or below normal and no excessively wet winter at any time during this long period, we must conclude that the similar period, devoid of winters with excessive rain, which we are now experiencing and which commenced about 1890, will certainly some day be followed by occasional winters with rainfall comparable with that of 1861–62 or perhaps even with a succession of very wet winters. Moreover no information is available which would permit a reasonable conjecture as to the length of time that the water of the lake covered the area on which the willows grew. This again was a long period. It must have commenced long before the first explorations of this region. Its commencement may have been in the eighteenth century or even earlier—probably not in the nineteenth for which contemporary or near contemporary records show unusually wet winters as follows: 1804–5, 1824–25, 1845–46, 1849–50, 1852–53, 1861–62, 1883–84, and 1889-90.

That there were in this nineteenth century also some very dry seasons is well known. Such for example was the winter of 1828–29 in which, as the mission records show, some 40,000 cattle died in the southern counties for lack of food and water; and the winter of 1863–64 with very little rainfall, disastrous to cattle and crops,

In this connection it may be recalled that the city of Szegedin in Hungary, after 100 years of protection against overflow, had its levees overtopped in 1879 by the high waters of the River Theis. So too, the recent high waters in southwestern France indicated heavier rainfall in that region than had been experienced since 1770. At Vienna on the Danube the greatest flood of which there is record occurred in the year 1501 or more than 400 years ago. Twice near the end of the last century the Danube reached stages at Vienna that were exceptionally high, but at which the volume of water brought down by the stream at its peak was only about three-fourths of that during



TULARE LAKE - WATER SURFACE ELEVATIONS, 1850-1930

intermediate between the two high stages of Tulare Lake above referred to. (See diagram showing the stage of Tulare Lake, 1849 to 1930, and seasonal rainfall in central portions of California.)

It appears from such evidence as the above that it would be improper to assume that, because California, considered in its entirety, has not had a very wet winter in recent years, the climate has changed and that never again will so much rain and snow fall as in the winter of 1861–62. On the contrary, the facts which have been cited should rather be taken to indicate that there may be many years in succession without excessive precipitation and that there may be other periods, perhaps centuries in duration, in which years or seasons with excessive or relatively high precipitation will be frequent.

the greatest flood in 1501. Many other instances could be cited of the long time interval between extreme rainfall and runoff conditions, going to show that no material change in historic times in the amount of rainfall to be expected in any locality should be assumed.

Even such facts as the retreat of the Alaskan glaciers, the gradual disappearance of glaciers on the slope of Mount Shasta, and of the recent sudden melting away of the Palisades Glacier (1924) on the eastern slope of the Sierra Nevada, should not be taken as conclusive evidence of a change in climate, but should rather be attributed to a sequence of years with deficient snowfall and more than normal summer heat—factors which are conducive to the shrinkage of the ice fields and which may be followed by another sequence of years in which conditions are reversed.